SOURCES OF VARIATION IN CATCH PER UNIT EFFORT OF YELLOWTAIL FLOUNDER, *LIMANDA FERRUGINEA* (STORER), HARVESTED OFF THE COAST OF NEW ENGLAND

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ABSTRACT

Factors affecting variability in commercial catch per unit effort (CPUE) of yellowtail flounder were examined in order to establish a basis for standardizing fishing effort. Analysis of variance (ANOVA) procedures were employed to test for differences in CPUE among vessel tonnage class, fishing area, and depth zone and the interactions between tonnage class and area, and tonnage class and depth. Vessel tonnage class and fishing area accounted for highly significant ($P < 0.01$) sources of variation in CPUE whereas depth was not significant ($P > 0.05$) in most cases. Interactions between tonnage class and stock area were also highly significant in all cases. A series of annual fishing power coefficients was computed for each tonnage class relative to a standard for each stock based on parameter estimates obtained by fitting the CPUE observations to a linear model with tonnage class as the independent variable. Deviations of annual fishing power coefficients from the 20-year mean were found to exhibit significant first order autocorrelations. Consequently, annual coefficients were computed over the entire 1964–83 period by incorporating tonnage class, annual and seasonal effects as independent variables in a three-way linear model. Although the standardized CPUE estimates obtained from this procedure are similar to those obtained by previous methods, the revised procedures described in this paper insure adequate representation of all vessel classes engaged in the yellowtail fishery in the CPUE calculations.

Fishing effort and resulting catch per unit effort (CPUE) indices are routinely used in assessing the impact of commercial fishing operations on stock abundance. The traditional concept that aggregate CPUE indices may be used to measure annual changes in relative stock abundance is based on the principal assumption that the catchability coefficient (q) either remains constant over all fleet components, or that nominal effort is adjusted to account for differences in relative efficiencies (Pope and Parrish 1964; Kimura 1981). Variation in q may be due to persistent differences in fishing power of various types of gear or to technological innovations which may be gradually introduced over time (Gulland 1964; Sissenwine 1978). Biological interactions such as changes in availability of a species due to seasonal distribution patterns or to annual changes in abundance may also affect the overall catchability of demersal species (Garrod 1964; Pope and Garrod 1975). Variability in catchability coefficients may be taken into account by relating nominal fishing effort of each fleet component to some chosen standard category.

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Numerous authors have described the basic procedures for calculating relative fishing power of various fleet components. Beverton and Holt (1957) provided evidence to suggest that the distribution of logarithms of fishing power factor/vessel tonnage ratios could be described by a normal curve while Gulland (1956) employed an analysis of variance (ANOVA) model of log CPUE. The properties of the ANOVA model were further examined by Robson (1966) who extended the techniques developed by Gulland (1956) and formally specified the analysis of Beverton and Holt (1957) as a two-way multiplicative ANOVA model. Stern and Hennemuth (1975) employed the method of Robson (1966) in their analysis of fishing effort in the U.S. Georges Bank haddock fishery using depth fished and vessel tonnage as classification variables. In a previous study, Rounsefell (1957) computed standardized log CPUE indices to determine relative abundance of several co-occurring species on Georges Bank according to depth. More recently, Gavaris (1980) and Kimura (1981) have developed modifications of the ANOVA model to estimate annual standardized CPUE indices from time series of catch and effort data by incorporating a year effect in the model.

Standardized annual CPUE indices based on

Manuscript accepted October 1987.
FISHERY BULLETIN: VOL. 86, NO. 1, 1988.

criteria established by Lux (1964) have been routinely used to monitor relative abundance of three stocks of yellowtail flounder, *Limanda ferruginea* (Storer), in the commercial fishery off the New England coast (Fig. 1). Lux calculated CPUE indices for otter trawlers ranging from <26 gross registered tons (GRT) to 100 GRT based on trips in which yellowtail flounder accounted for 50% or more of the total landed weight between 1942 and 1961. A fishing power coefficient was then computed for each of several GRT categories as the ratio of CPUE to a standard GRT category CPUE for the entire timespan. A separate set of fishing power coefficients was computed for each of the three stocks. Lux's (1964) work improved upon an earlier analysis of yellowtail flounder CPUE by Royce et al. (1959) which was based only on relatively small vessels ranging in size from 5 to 50 GRT that dominated the fishery during the 1940's.

Since 1964, numerous technological innovations have drastically changed the character of the New England fishing fleet as traditional side trawlers have gradually given way to larger, more efficient stern trawlers equipped with sophisticated electronic navigation and hydroacoustic devices. This gradual alteration in the fleet characteristics over time suggests that previously documented relationships among vessel categories may no longer be applicable to the current fishery, and that use of nominal effort in CPUE calculations will tend to overestimate relative abundance in the more recent years (Westrheim and Foucher 1985). Long-term declines in yellowtail flounder abundance on each of the principal fishing grounds (Clark et al. 1984) also indicate that current catchability coefficients may differ from previous values. Accordingly, updated fishing power coefficients are required to adequately assess changes in effective fishing effort and CPUE which have occurred during the past two decades. Further, to obtain annual effort and CPUE estimates over such a broad period of years, techniques for computing relative fishing power should incorporate a time element in the analysis.

In this paper we examine variation in CPUE with respect to fishing area, depth, vessel tonnage class, season, and year for three stocks of yellowtail flounder on Georges Bank, Southern New England, and Cape Cod grounds between 1964 and 1983. Before evaluating differences in relative fishing power among vessel classes, we investigate potential interactions between tonnage class and area and tonnage class and depth within each year, and partition the data to minimize tonnage class-area interactions. For each stock, fishing power coefficients are examined for

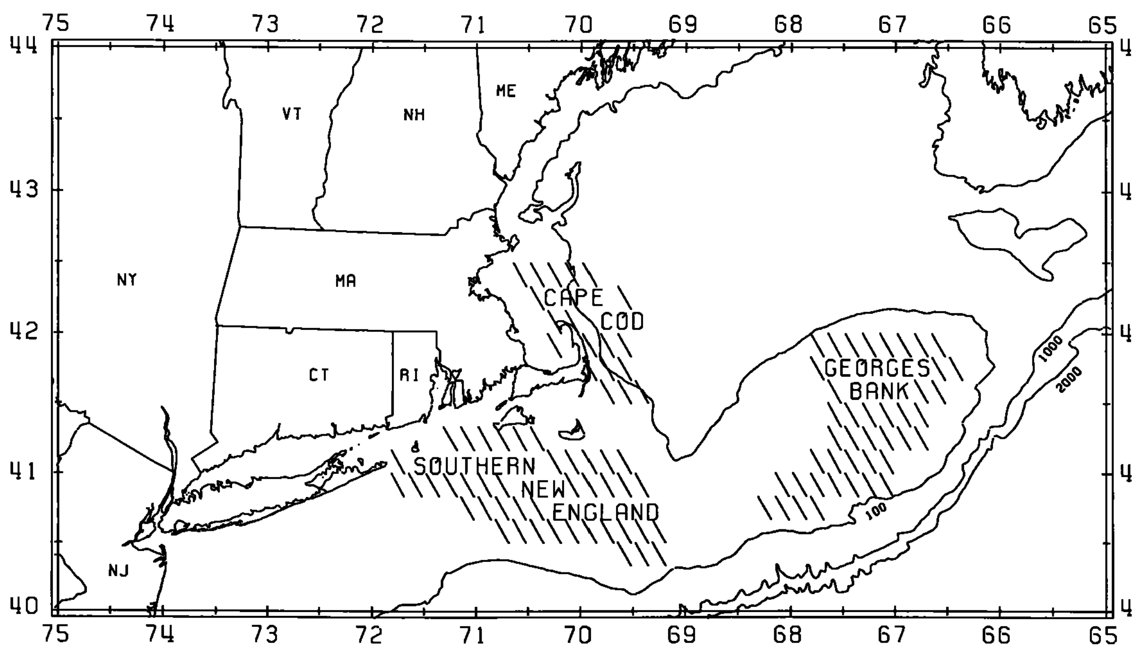

FIGURE 1.—Yellowtail flounder stocks off the coast of New England (After Lux 1963).

annual and seasonal interactions. A three-way linear model, incorporating annual and seasonal components, is employed to compute relative fishing power coefficients over the entire 20-yr period and estimate annual standardized CPUE indices.

DISTRIBUTION OF CATCH AND EFFORT

Commercial exploitation of yellowtail flounder began in the late 1930's following the decline of the winter flounder fishery (Royce et al. 1959). Nominal catches[2] for the three grounds combined rapidly increased to 31,500 metric tons (t) in 1942 but subsequently declined to 5,500 t in 1954. Landings by U.S. vessels gradually increased to a record high of 36,900 t in 1963, but declined again to 10,500 t in 1978 (Fig. 2). Distant water fleet (DWF) catches were also substantial during this period, peaking at 20,700 t in 1969. Overall catches from the three fishing grounds have recently increased to 30,800 t in 1983, although 1984 landings declined to 15,500 t (Clark et al. 1984). The decline in catch during the 1940's was not due to overfishing (Royce et al. 1959) but may have been related to a warming trend in the region which affected recruitment (Sissenwine 1974). The more recent decline between 1969 and 1978, however, has been attributed to increased fishing effort by both domestic and distant water fleets (Brown et al. 1980).

In the early 1940's the size of vessels fishing for yellowtail flounder varied from 5 to 75 GRT. The predominant vessels on Southern New England and Cape Cod grounds ranged from 26 to 50 GRT; on Georges Bank, the dominant vessels were in the 51–75 GRT range. By the mid-1960's larger vessels had begun to enter the fishery, increasing the maximum size to 215 GRT. During this period the size range of the dominant vessels on Southern New England grounds and on Georges Bank had increased to 51–72 and 73–104 GRT, respec-

[2]Nominal catch defined as live weight equivalent of landings, excluding discards.

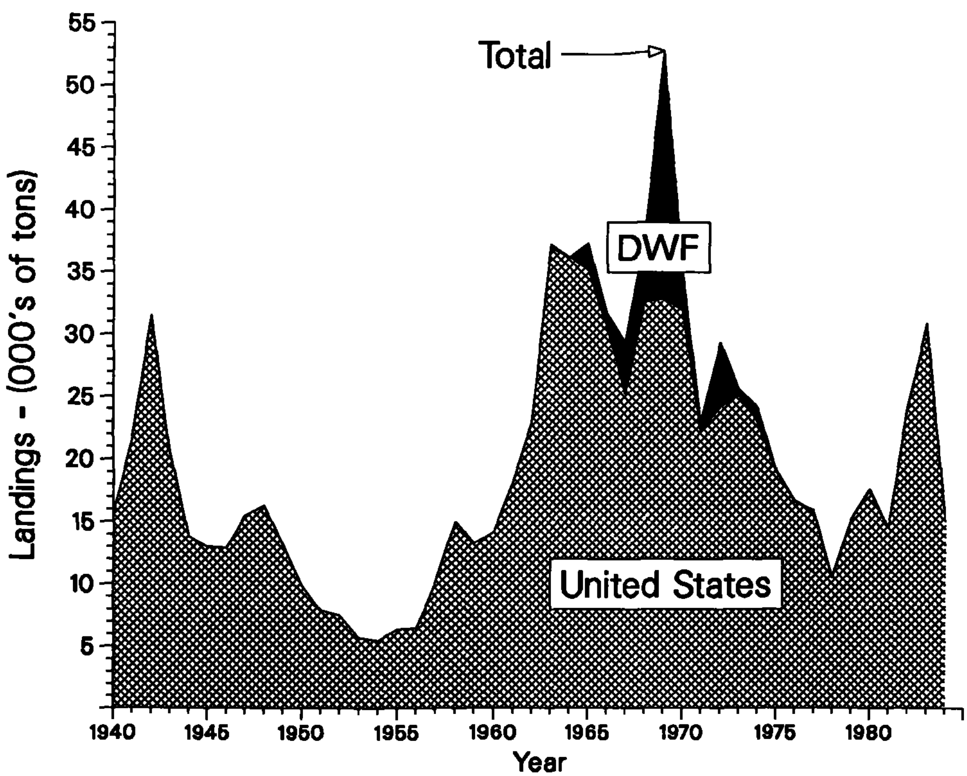

FIGURE 2.—Yellowtail flounder landings (metric tons) by United States and distant water fleet (DWF) vessels from the combined Georges Bank, Southern New England, and Cape Cod grounds, 1940–84.

tively. Vessels fishing the relatively nearshore Cape Cod grounds remained in the 34–50 GRT range. Larger vessels continued to enter the fishery during the 1970's and, by 1983, several vessels were in the 311–400 GRT range. Since 1964, vessel GRT's have been categorized by tonnage class (TC) as given in Table 1a.

A review of Lux's (1964) data from 1942 to 1961 and the distribution of more recent yellowtail flounder landings from 1964 to 1983 (Figs. 3–5) reveal that vessels of similar size have continually fished the same general areas over the past 40 years. The TC 21–24 vessels fish primarily on Southern New England and Cape Cod grounds (Fig. 3), although TC 24 vessels occasionally enter the southwest part of Georges Bank. The TC 25–33 vessels fish on both Georges Bank and Southern New England grounds (Fig. 4), while TC 41–43 vessels concentrate on Georges Bank (Fig. 5). Although TC 41 vessels operate at times on the eastern part of the Southern New England grounds, the TC 42 and 43 vessels fish exclusively on Georges Bank.

The distribution plots (Figs. 3–5) reveal a gradual phaseout of smaller (TC 21–24) vessels on the inshore Southern New England and Cape Cod grounds and a concurrent increase in the activity of large (TC 41–43) vessels on Georges Bank, Southern New England, and, to a lesser extent, on the Cape Cod grounds. In evaluating trends in CPUE we must ask whether these changes in the yellowtail fishery over the past 20 years (i.e., the shift in the predominant vessel size on two of the three grounds and the addition of larger vessels to the fleet on all three grounds) affect CPUE as calculated by the traditional method (Lux 1964). If the same size range of vessels (5–100 GRT) had fished for yellowtail flounder throughout the years, a shift in the dominant vessel class would not affect CPUE estimates since effort would be standardized against the same class and is, therefore, relative. However, the maximum vessel size has increased and the predominant TC now represents vessels larger than 100 GRT. Since landings and effort data contributed by these larger vessels were not incorporated into previous CPUE calculations, CPUE estimates will not necessarily represent overall fleet performance in recent years. The following procedures, therefore, were developed to calculate new fishing power coefficients that encompass the entire size range of vessels currently in the fishery.

TABLE 1.—Definition of vessel tonnage classes (a) and depth ranges and corresponding zones (b) included in analysis of variance of yellowtail flounder CPUE.

	Gross registered tonnage (range)	Vessel tonnage class
a		
	5–10	21
	11–15	22
	16–22	23
	23–33	24
	34–50	25
	51–72	31
	73–104	32
	105–150	33
	151–215	41
	216–310	42
	311–400	43
b	Depth range (m)	Depth zone
	1–55	1
	56–110	2
	111–183	3

METHODS OF ANALYSIS

Catch and effort data recorded by trip were obtained from Northeast Fisheries Center (NEFC) detailed commercial landings files. Fishing effort or days fished (df) is defined on a 24-h basis as number of hours of actual fishing time divided by 24. Only trips landing 50% or more of yellowtail flounder were analyzed; trips included within the qualification level generally accounted for 70–90% of the total yellowtail landings over the entire period, except on Cape Cod grounds where qualified trips accounted for 40–60% of the total. Catch per day fished (CPUE) was computed for each trip and transformed to ln CPUE since preliminary analysis indicated a positive correlation of the arithmetic mean CPUE with the variance. Use of the log transformation, however, stabilized the variance and created a lognormal distribution as noted by Gulland (1956) and Steel and Torrie (1980).

Trips landing between 1964 and 1983 are classified in the data base by vessel tonnage class, statistical area, and depth zone fished. Vessels ranging in size from 5 to 310 GRT (Table 1a) and statistical areas corresponding to the three major stocks were selected for analysis as follows: Georges Bank (areas 522–525), Southern New England (area 526 and 537–539), and Cape Cod (areas 514 and 521) (Fig. 6). Because of their sporadic representation, TC 21–23 vessels have been excluded from the Georges Bank analyses and have been combined as one category on the Southern New England grounds. Depth zones 1, 2, and

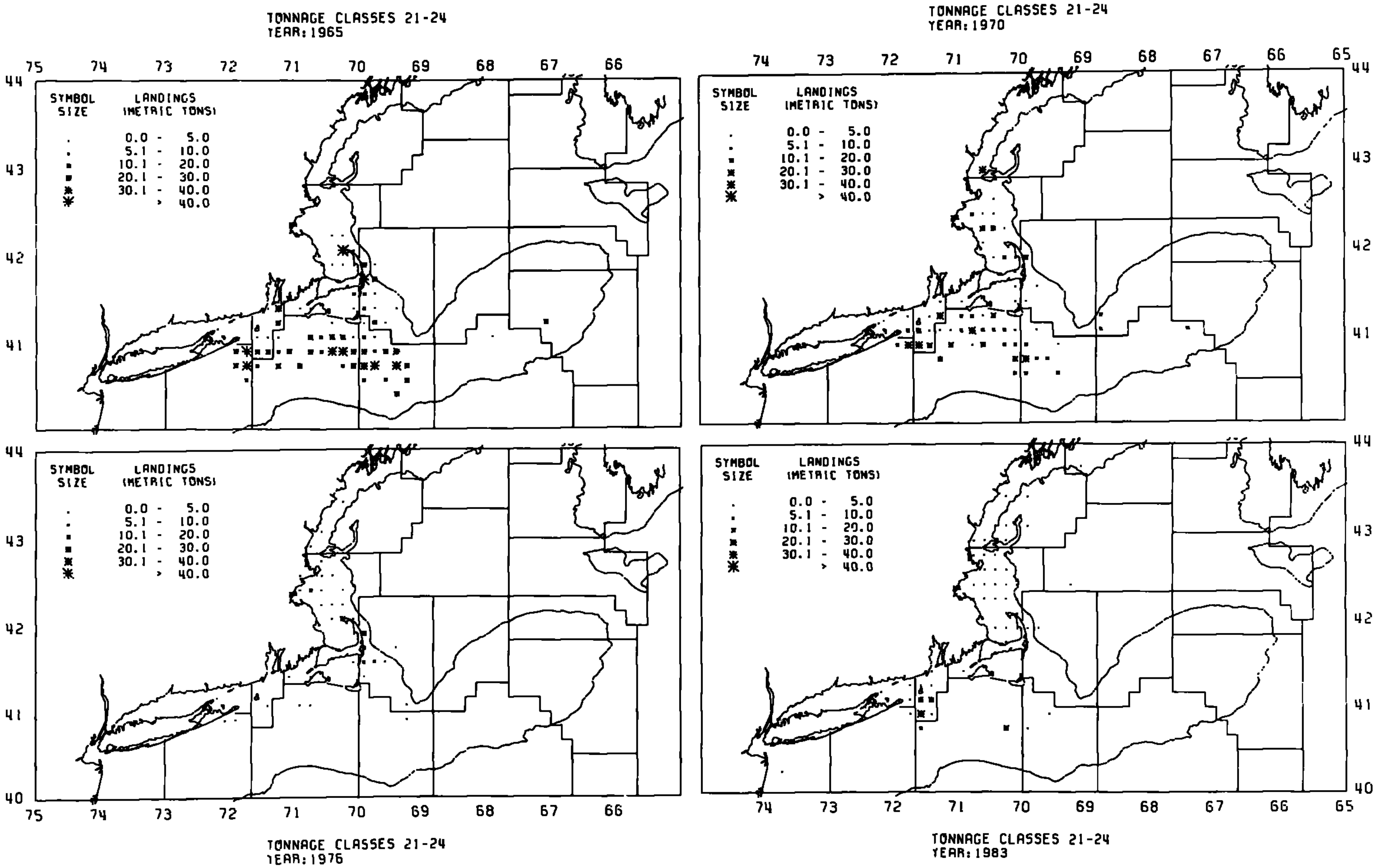

FIGURE 3.—Distribution of yellowtail flounder landings in 1965, 1970, 1976, and 1983 for vessel tonnage classes 21–24.

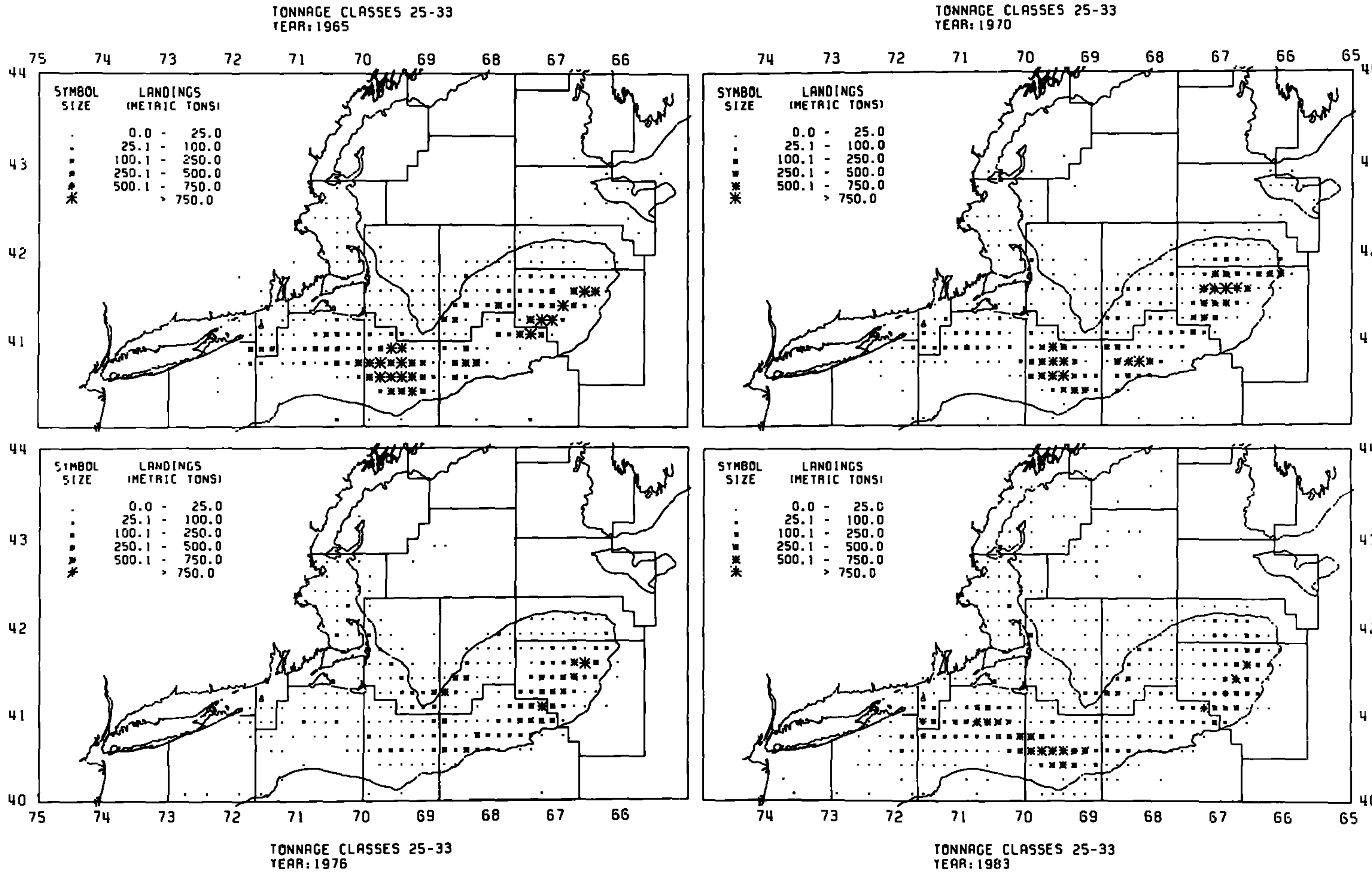

FIGURE 4.—Distribution of yellowtail flounder landings in 1965, 1970, 1976, and 1983 for vessel tonnage classes 25–33.

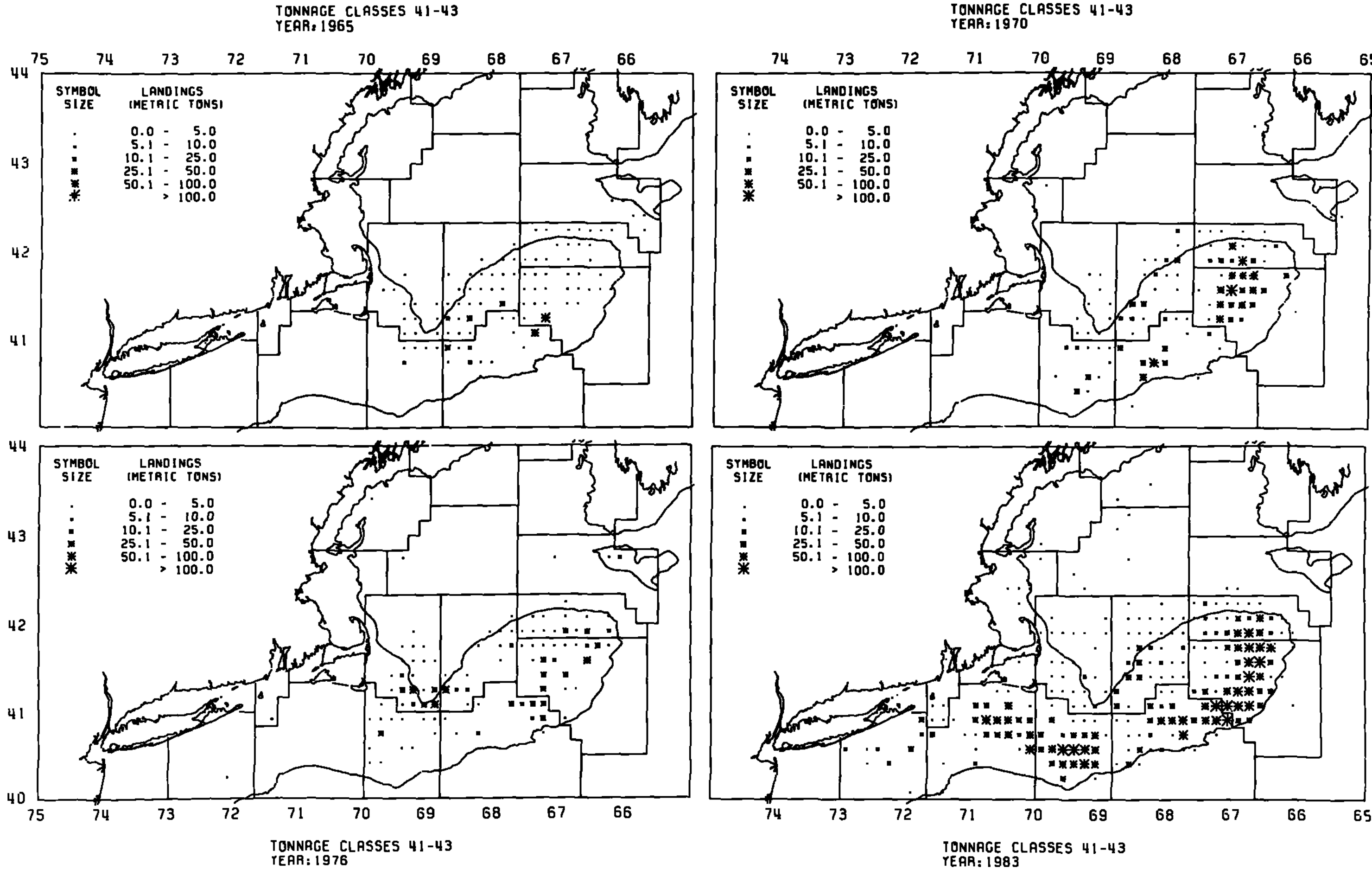

FIGURE 5.—Distribution of yellowtail flounder landings in 1965, 1970, 1976, and 1983 for vessel tonnage classes 41–43.

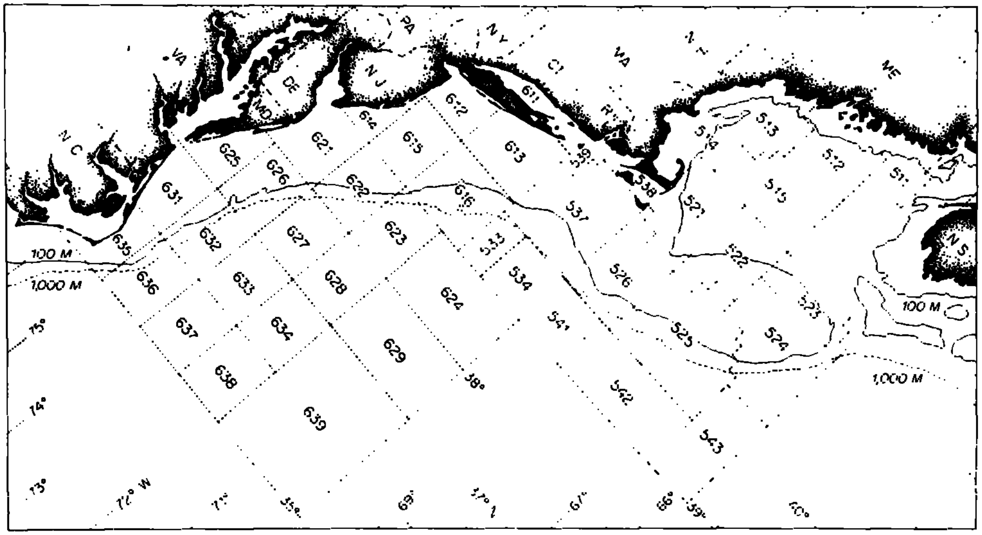

FIGURE 6.—Yellowtail flounder fishing grounds defined by U.S. statistical area are as follows: Southern New England, 526–539; Georges Bank, 522–525; Cape Cod, 514 and 521.

3 (Table 1b) were also selected from six possible zones based on the bathymetric distribution of yellowtail flounder.

Trip data were aggregated at different levels of spatial resolution to examine variability in CPUE over the entire region and within each of the three established stocks. Two-way ANOVAs with interaction were performed on annual data sets using the BMDP statistical software program P4V (Dixon 1981). Given the large number of observations in each analysis, the more rigorous 99% significance level was chosen to test the null hypothesis (no significant differences) since relatively small differences in mean CPUE can produce statistically significant results. The ANOVA was performed initially to test for differences in CPUE among all tonnage classes and statistical areas and to determine the overall extent of tonnage class-area interactions. Secondary analyses were performed to examine the effect of tonnage class-area and tonnage class-depth interactions among and within each of the stocks. All subsequent tests for significance of tonnage class, area, and depth main effects were performed with the interaction effects absorbed in the error sum of squares. Estimates of annual geometric mean CPUE were obtained by combinations of tonnage class, stock area, and depth from the row and column means provided by the P4V software (Tables 2, 3).

A standard vessel class was selected for each of the three stocks for use in calculation of fishing power coefficients based on the prevalence of the vessel class in the fishery and its relative contribution to the landings over the 20 years. The TC 32 category was chosen as the standard for both Georges Bank and Southern New England stocks, and the TC 25 class was chosen as the standard for the Cape Cod stock. Within each stock annual fishing power coefficients were derived for each tonnage class relative to the standard by fitting ln CPUE to a one-way linear model using the GLM procedure of the Statistical Analysis System (SAS Institute 1982) as follows:

$$U = \alpha + \sum_j [\beta_j X_j] + \epsilon.$$

Annual deviations of the coefficients from the 20-yr mean were tested for first order autocorrelation using the Durbin-Watson test statistic (Neter and Wasserman 1974). A time component was subsequently incorporated in the linear model to account for annual trends in the data; seasonal effects were also included by classifying the data according to calendar quarter. The initial year (1964) and the fourth quarter were selected as reference categories. The general model is specified as:

TABLE 2.—Geometric mean CPUE[1] (landings per day fished, metric tons) for Georges Bank, Southern New England, and Cape Cod yellowtail flounder trips by vessel tonnage class, 1964–83.

	Vessel tonnage class									
Year	21	22	23	24	25	31	32	33	41	42
					Georges Bank					
1964	—	—	—	3.65	4.17	4.88	5.04	4.58	4.52	2.14
1965	—	—	—	2.41	3.06	3.62	3.55	3.39	4.97	—
1966	—	—	1.18	1.25	2.27	2.76	2.78	2.76	2.71	—
1967	—	—	—	—	2.20	2.74	2.96	2.78	2.65	—
1968	—	—	—	3.88	2.99	3.47	3.55	3.84	3.53	2.66
1969	—	—	—	3.28	2.82	3.06	3.30	3.02	2.81	3.88
1970	—	—	—	3.74	2.40	2.88	3.08	2.81	2.70	—
1971	—	—	—	1.66	2.07	2.70	2.52	2.24	2.35	—
1972	—	—	—	—	1.96	2.24	2.39	2.29	1.96	—
1973	—	—	—	1.38	2.64	2.61	2.81	3.05	2.76	3.20
1974	—	2.52	—	—	2.79	2.13	2.23	2.19	1.30	3.42
1975	—	—	—	1.93	1.91	1.64	1.93	2.04	1.72	3.19
1976	—	—	—	1.35	1.69	1.77	1.84	2.16	2.06	—
1977	—	—	—	—	1.17	1.66	1.77	2.26	1.81	—
1978	—	—	—	—	1.67	1.50	1.72	2.03	2.82	—
1979	—	2.69	—	1.31	1.80	2.41	2.37	2.82	3.64	—
1980	—	0.30	—	1.09	0.90	2.88	2.62	3.27	3.00	—
1981	—	—	—	1.12	1.24	1.98	2.48	2.61	2.23	—
1982	—	—	1.88	0.48	2.02	1.71	2.10	2.53	3.97	2.07
1983	—	—	—	—	0.79	2.46	1.97	2.21	3.79	—
					Southern New England					
1964	2.34	1.94	6.15	4.88	4.66	4.44	5.04	4.59	4.09	—
1965	1.77	1.55	3.87	3.62	3.12	3.56	3.81	4.05	1.50	—
1966	1.21	3.06	3.19	2.93	2.52	2.61	2.56	2.35	3.03	—
1967	1.80	1.14	2.94	3.38	3.23	2.67	2.66	2.31	1.80	—
1968	2.24	4.15	4.69	4.42	4.02	3.41	3.62	3.63	3.53	—
1969	2.65	3.72	5.17	3.81	4.10	3.39	3.43	4.01	2.81	—
1970	7.74	3.28	4.76	3.77	3.96	3.08	3.64	2.87	2.70	—
1971	11.72	1.60	4.06	3.14	3.32	2.85	2.87	3.16	2.35	—
1972	—	1.96	3.19	2.62	3.30	3.01	2.96	3.04	1.96	—
1973	—	1.01	1.05	2.26	2.66	2.29	2.22	2.12	2.76	—
1974	—	1.08	1.62	2.31	2.14	2.07	2.07	2.64	1.30	—
1975	—	0.57	1.57	1.13	1.29	1.33	1.55	1.55	1.72	—
1976	—	0.72	0.90	0.53	0.86	1.13	1.32	1.69	2.06	—
1977	—	0.93	1.73	1.44	1.77	1.61	1.82	1.98	1.81	—
1978	—	—	2.72	1.15	1.58	1.52	2.04	2.26	2.82	—
1979	0.79	1.74	2.28	1.59	2.17	2.32	2.93	2.88	3.64	—
1980	—	1.02	2.46	1.91	2.54	2.68	2.81	3.07	3.00	—
1981	—	1.88	2.50	1.43	2.58	2.76	2.61	3.28	2.23	—
1982	2.49	1.96	2.42	2.29	3.10	3.20	3.72	3.98	3.97	—
1983	8.81	1.74	2.51	3.35	3.43	3.27	3.65	3.57	3.79	—
					Cape Cod					
1964	—	1.65	1.38	1.94	2.64	2.85	2.76	—	—	—
1965	—	1.45	1.20	1.59	2.16	3.56	2.12	2.07	—	—
1966	1.13	1.07	1.23	1.48	2.55	3.64	1.76	—	—	—
1967	—	0.78	0.90	1.56	2.46	3.21	1.95	2.62	—	—
1968	—	1.16	0.99	1.89	2.65	4.11	2.42	—	1.13	—
1969	—	1.66	1.33	2.02	2.77	3.64	2.47	—	—	—
1970	—	1.03	1.05	2.34	2.33	3.64	[2]6.96	[2]34.18	2.91	—
1971	—	1.17	1.89	2.43	2.04	2.24	1.90	2.45	3.36	—
1972	1.71	1.63	1.16	2.02	1.85	2.02	1.46	1.79	1.93	—
1973	1.02	1.32	1.06	1.87	1.99	1.90	1.91	1.63	2.84	—
1974	0.83	1.15	0.90	1.59	2.08	1.74	1.82	1.87	1.37	—
1975	0.77	1.13	1.23	1.42	1.92	1.45	1.64	1.09	1.19	—
1976	0.34	1.31	1.38	1.69	1.93	1.42	1.54	1.88	2.15	—
1977	0.28	0.86	1.25	1.50	2.03	1.45	1.42	2.19	2.57	—
1978	—	0.84	1.59	1.90	2.11	1.96	1.53	1.92	5.99	—
1979	0.98	0.91	1.42	1.83	2.10	2.24	1.74	2.23	3.12	—
1980	0.26	0.58	1.30	1.73	2.18	2.24	2.07	2.19	3.34	—
1981	0.70	0.76	1.17	1.69	2.24	2.40	1.22	1.85	2.99	—
1982	0.54	0.71	1.22	1.79	2.02	2.41	1.57	1.94	2.37	—
1983	0.69	1.51	1.23	1.96	1.91	1.29	1.53	1.46	0.83	—

[1]Calculated as $\exp\left[1/n \cdot \Sigma \ln\left(\frac{\text{landings}}{\text{effort}}\right)\right]$

[2]Only one trip by tonnage classes 32 and 33 in 1970 on Cape Cod grounds.

$$U = \alpha + \sum_{ij} [\beta_{ij} X_{ij}] + \epsilon$$

where U = ln CPUE,

α = intercept estimate,

β_{ij} = model parameter estimates in logarithmic units for category j for tonnage class, season, and year,

X_{ij} = dummy variable for tonnage class, season, and year (=1 when category j occurs; = 0 otherwise), and

ϵ = error term.

All tests for significance of main effects were based on the above model without interaction. Separate ANOVAs were also performed to examine first order interactions. Parameter estimates obtained from the model without interaction were retransformed following methods described by Bradu and Mundlak (1970) to derive unbiased fishing power, seasonal, and annual coefficients. Annual coefficients corresponding to the 1965–83 period were multiplied by the reference year CPUE to compute annual standardized CPUE estimates.

RESULTS

Smaller vessels (TC 21–24) generally exhibited the lowest CPUE indices in all three areas, although TC 21–23 vessels were not represented on Georges Bank (Table 2). Catch rates of medium vessels (TC 25; 31–33) were similar to each other, and were generally greater than those for TC 21–24 vessels. Mean CPUE indices for the largest vessels (TC 41 and 42) were more variable, but generally were equal to or greater than those

TABLE 3.—Geometric mean CPUE[1] (landings per day fished, metric tons) for Georges Bank, Southern New England, and Cape Cod yellowtail flounder trips by depth zone, 1964–83.

	Georges Bank				Southern New England				Cape Cod			
	Depth zone				Depth zone				Depth zone			
Year	1	2	3	Combined	1	2	3	Combined	1	2	3	Combined
1964	3.92	4.91	2.74	4.80	5.05	4.96	4.71	5.03	2.13	2.36	—	2.25
1965	3.76	3.48	—	3.55	3.61	3.88	2.28	3.66	1.61	1.80	2.36	1.71
1966	3.02	2.62	1.29	2.71	2.71	2.66	0.71	2.71	1.99	2.13	1.70	2.07
1967	3.19	2.69	2.81	2.79	2.97	2.77	1.14	2.91	1.52	2.16	—	1.80
1968	3.38	3.51	—	3.49	3.70	3.97	3.24	3.76	2.15	2.31	—	2.24
1969	3.36	3.11	—	3.16	3.62	3.93	1.58	3.66	2.16	2.66	—	2.27
1970	2.81	2.99	1.00	2.93	3.44	3.68	1.62	3.49	1.10	2.24	[2]34.18	1.40
1971	2.20	2.30	2.75	2.28	3.26	2.96	—	3.14	1.03	1.94	—	1.46
1972	2.28	2.37	1.34	2.35	3.28	3.25	2.74	3.27	1.56	1.88	—	1.82
1973	2.30	3.06	2.85	2.91	2.41	2.55	4.40	2.47	1.75	1.83	2.27	1.81
1974	2.10	2.32	2.90	2.30	2.31	2.02	—	2.19	1.86	1.78	—	1.82
1975	1.85	1.99	1.29	1.98	1.59	1.63	—	1.60	1.53	1.38	1.32	1.46
1976	1.75	2.06	—	2.03	1.34	1.56	—	1.43	1.54	1.88	2.93	1.70
1977	1.92	2.15	1.67	2.14	1.92	1.97	—	1.94	1.70	1.89	1.27	1.77
1978	1.78	2.09	1.98	2.07	2.45	2.17	—	2.32	1.90	1.71	3.49	1.86
1979	2.47	2.79	2.04	2.74	2.88	2.39	—	2.76	2.03	2.03	2.47	2.03
1980	2.58	3.50	1.53	3.37	2.71	3.51	1.13	3.04	2.06	2.31	2.38	2.16
1981	2.26	2.88	1.54	2.76	2.46	2.78	—	2.58	1.74	1.96	5.67	1.79
1982	2.34	2.66	2.53	2.62	3.20	3.54	4.53	3.31	1.81	1.44	0.91	1.67
1983	1.98	2.28	3.04	2.26	3.08	3.13	5.91	3.10	1.70	1.41	—	1.62

[1]Calculated as $\exp\left[1/n \cdot \Sigma \ln\left(\frac{\text{landings}}{\text{effort}}\right)\right]$.

[2]Only one trip in depth zone 3 in 1970 on Cape Cod grounds.

corresponding to medium and small vessels, particularly in the later years (Table 2). The initial ANOVAs performed over all statistical areas revealed highly significant ($P < 0.01$) differences in CPUE for tonnage class and area main effects in each of the 20 years (Table 4). The interaction of tonnage class and area was also highly significant in all years, suggesting that relative fishing power of the individual vessel classes varies according to area. ANOVA results for the comparison of CPUE among stocks were highly significant for area main effects in 19 out of 20 years, and the tonnage class-stock area interaction term was highly significant in all years (Table 4). Grouping the data according to stock tended to reduce the amount of significant tonnage class-area interaction within each stock, although differences among tonnage classes remained highly significant.

On Georges Bank the differences in CPUE were highly significant for statistical area and tonnage class main effects in 80 and 100% of the years, respectively, while the tonnage class-area interaction was highly significant in only 40% of the years. Differences due to area on Southern New England grounds were highly significant in all years except 1978, and differences due to tonnage class were highly significant in all years. The interaction term was highly significant in 70% of the years. Differences due to area on the Cape Cod grounds were highly significant in all years except 1975, and differences due to tonnage class were highly significant for all years. The interaction was highly significant in only 35% of the years (Table 4).

Differences in CPUE by depth zone were generally not significant. Depth main effects yielded

TABLE 4.—Frequency with which highly significant ($P < 0.01$) results were obtained from analysis of variance (ANOVA) tests of yellowtail flounder annual CPUE data. (Total number of years tested = 20.) N/A = Not applicable (tests not performed).

	Main effects		
	Area	Tonnage class	Depth
All areas	20/20	20/20	N/A
Among stocks	19/20	N/A	N/A
Within stocks			
Georges Bank	16/20	20/20	10/20
So. New England	19/20	20/20	7/20
Cape Cod	19/20	20/20	3/20

	Interactions	
	Tonnage class × area	Tonnage class × depth
All areas	20/20	N/A
Among stocks	20/20	N/A
Within stocks		
Georges Bank	8/20	4/20
So. New England	14/20	2/20
Cape Cod	7/20	1/20

highly significant differences in only 50, 35, and 15% of the years for Georges Bank, Southern New England, and Cape Cod grounds, respectively (Table 4), while the tonnage class-depth interaction was highly significant in no more than 20% of the years on each of the three grounds.

Interaction between tonnage class and statistical area throughout the region was highly significant in all cases. Further analyses yielded highly significant differences in CPUE among the three stocks and highly significant tonnage class-stock interactions which suggests that relative fishing power among vessel classes is not consistent from stock to stock, implying a need for computing a separate set of fishing power coefficients for each stock. Within each stock, differences in CPUE among statistical areas and tonnage classes were also highly significant in most cases, although the tonnage class-area interaction was not.

Standardized CPUE

Annual fishing power coefficients, obtained by retransforming linear model parameter estimates for each tonnage class, are presented in Table 5 by stock. Cursory examination of the coefficients reveals distinct trends throughout the 20-yr series. On Georges Bank and Southern New England grounds, fishing power coefficients for the smaller vessels (TC 23–25) relative to the standard declined over time, whereas coefficients for the larger vessels increased over time. On Cape Cod grounds the coefficients increased for the smaller vessels (TC 23 and 24) although trends were less pronounced. These trends are illustrated graphically by plotting annual deviations from the 20-yr average in Figures 7–9. A Durbin-Watson test for first order autocorrelation of the annual deviations (Neter and Wasserman 1974) was significant for most tonnage classes within each of the stocks, suggesting the presence of a substantial tonnage class-time interaction.

The three-way linear model, modified to include interaction terms, also revealed highly significant tonnage class-year as well as tonnage class-season and year-season interactions within each of the three stocks (Table 6). When interactions are significant, they can be examined in detail or absorbed in the error term when testing for main effects. Since tonnage class effects have already been examined on an annual basis, the interaction terms were excluded from the three-way model used to obtain parameter estimates for tonnage class, season, and year. The model is specified as follows:

$$U = \alpha + \sum_j [\beta_{1j} X_{1j} + \beta_{2j} X_{2j} + \beta_{3j} X_{3j}] + \epsilon$$

where $\beta_{1j}, \beta_{2j}, \beta_{3j}$ = model parameter estimates in logarithmic units for category j for tonnage class, season, and year,

X_{1j}, X_{2j}, X_{3j} = dummy variables for tonnage class, season, and year (= 1 when category j occurs; = 0 otherwise).

ANOVA results obtained without interaction are presented in Table 6 for each of the three stocks. For Georges Bank and Southern New England stocks, year accounts for the greatest reduction in error sums of squares; on Cape Cod grounds tonnage class accounts for the greatest overall reduction.

Coefficients for tonnage class, year, and season, derived from model parameter estimates for the combined 1964–83 period are presented in Table 7. Tonnage class coefficients for Georges Bank and Southern New England are relatively homogeneous, as compared with those obtained for Cape Cod grounds, owing to the narrower range of vessel tonnage classes which have consistently exploited these fisheries. Seasonal coefficients exhibit the same pattern on Georges Bank and Southern New England with the highest catch rates occurring during the third quarter; on Cape Cod grounds the highest catch rates occur during the second quarter. Trends in annual coefficients are similar on all three grounds. Standardized CPUE indices based on the annual coefficients are illustrated in Figure 10, and traditional indices based on the methods of Lux (1964), as given by Clark et al. (1984), are also presented for comparative purposes.

Although each series indicates similar trends, CPUE indices obtained from the linear model for Georges Bank and Southern New England have remained slightly higher than the traditional indices since the early 1970's. Prior to this, the traditional CPUE indices were greater than the revised indices. On Cape Cod grounds, differences between the two series are considerably greater, particularly in the early years.

TABLE 5.—Annual fishing power coefficients calculated by vessel tonnage Georges Bank, Southern New England,

Year	Vessel tonnage class[1] 21	22	23	24	25	31	32	33	41	42
				Georges Bank						
1964				0.73	0.83	0.97		0.91	0.90	0.43
1965				0.68	0.86	1.02		0.95	1.40	—
1966				0.45	0.81	0.99		0.99	0.97	—
1967				—	0.74	0.93		0.94	0.89	—
1968				1.09	0.84	0.98		1.08	0.88	0.75
1969				0.99	0.85	0.93		0.92	0.95	1.17
1970				1.21	0.78	0.94		0.91	0.94	0.92
1971				0.66	0.82	1.07		0.89	1.12	—
1972				—	0.82	0.94		0.96	0.93	—
1973		not		0.49	0.94	0.93	1.00	1.09	1.09	1.14
1974		calculated		—	1.25	0.96		0.98	0.97	1.53
1975				1.00	0.99	0.85		1.06	1.04	1.66
1976				0.73	0.92	0.96		1.17	1.01	—
1977				—	0.66	0.94		1.28	1.67	—
1978				—	0.97	0.87		1.18	1.54	—
1979				0.55	0.76	1.02		1.19	1.35	—
1980				0.42	0.35	1.10		1.25	1.43	—
1981				0.45	0.50	0.80		1.05	1.16	—
1982				0.23	0.96	0.82		1.21	1.41	0.99
1983				—	0.40	1.25		1.12	1.26	—
				Southern New England						
1964	—	[2]0.95	—	0.97	0.92	0.88		0.91	0.81	
1965	—	0.86	—	0.95	0.82	0.93		1.06	0.39	
1966	—	1.12	—	1.14	0.98	1.02		0.92	1.18	
1967	—	0.94	—	1.27	1.22	1.00		0.87	0.68	
1968	—	1.21	—	1.23	1.11	0.94		1.01	0.98	
1969	—	1.32	—	1.11	1.19	0.99		1.17	0.82	
1970	—	1.23	—	1.04	1.09	0.85		0.79	0.74	
1971	—	1.06	—	1.10	1.16	0.99		1.10	0.82	
1972	—	0.99	—	0.88	1.12	1.01		1.03	0.66	
1973	—	0.46	—	1.01	1.20	1.03	1.00	0.95	1.24	

[1]Standard vessel class on Georges Bank and Southern New England rounds = 32. Standard vessel class on Cape Cod grounds = 25.

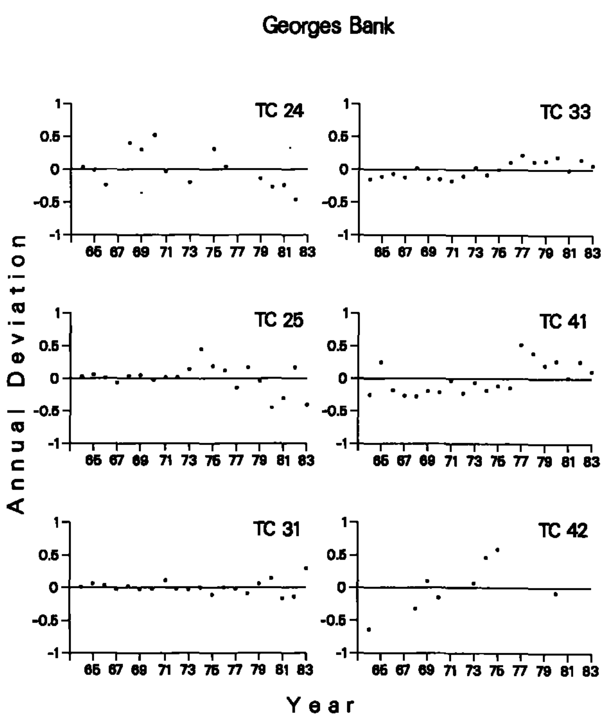

FIGURE 7.—Deviations in annual fishing power from the 1964–83 20-yr mean for major vessel tonnage classes fishing on Georges Bank.

class relative to a standard class vessel fishing for yellowtail flounder on and Cape Cod grounds, 1964–83.

Year	Vessel tonnage class[1] 21	22	23	24	25	31	32	33	41	42
				Southern New England						
1974	—	0.67	—	1.11	1.03	1.00		1.27	0.62	
1975	—	0.72	—	0.73	0.83	0.85		1.00	1.11	
1976	—	0.66	—	0.40	0.66	0.86		1.28	1.56	
1977	—	0.87	—	0.79	0.97	0.88		1.09	0.99	
1978	—	1.33	—	0.56	0.78	0.75		1.11	1.38	
1979	—	0.69	—	0.54	0.74	0.79		0.98	1.24	
1980	—	0.82	—	0.68	0.90	0.95		1.09	1.07	
1981	—	0.92	—	0.55	0.99	1.06		1.26	0.86	
1982	—	0.64	—	0.62	0.84	0.86		1.07	1.07	
1983	—	0.68	—	0.92	0.94	0.89		0.98	1.04	
				Cape Cod						
1964	—	0.62	0.52	0.73		1.08	1.04	—	—	
1965	—	0.67	0.55	0.73		1.65	0.98	0.96	—	
1966	0.44	0.42	0.48	0.58		1.42	0.69	—	—	
1967	—	0.32	0.36	0.64		1.30	0.79	1.07	—	
1968	—	0.44	0.37	0.71		1.55	0.91	0.99	0.43	
1969	—	0.60	0.48	0.73		1.31	0.89	—	—	
1970	—	0.44	0.45	1.01		1.56	([3])	([3])	1.25	
1971	—	0.57	0.93	1.19		1.10	0.93	1.20	1.65	
1972	0.93	0.88	0.63	1.09		1.09	0.79	0.97	1.05	
1973	0.51	0.66	0.53	0.94	1.00	0.95	0.96	0.82	1.43	
1974	0.40	0.55	0.43	0.76		0.83	0.87	0.90	0.66	
1975	0.40	0.59	0.64	0.74		0.75	0.85	0.57	0.62	
1976	0.18	0.68	0.72	0.88		0.73	0.80	0.97	1.12	
1977	0.14	0.42	0.61	0.74		0.71	0.70	1.08	1.26	
1978	—	0.40	0.75	0.90		0.93	0.73	0.91	2.84	
1979	0.47	0.43	0.68	0.87		1.06	0.83	1.06	1.48	
1980	0.12	0.27	0.60	0.80		1.03	0.95	1.01	1.53	
1981	0.31	0.34	0.52	0.75		1.07	0.54	0.83	1.34	
1982	0.27	0.35	0.60	0.88		1.19	0.77	0.96	1.17	
1983	0.36	0.79	0.64	1.02		0.68	0.80	0.77	0.43	

[2]Vessel classes 21, 22, and 23 combined on Southern New England grounds.

[3]Insufficient data for these categories.

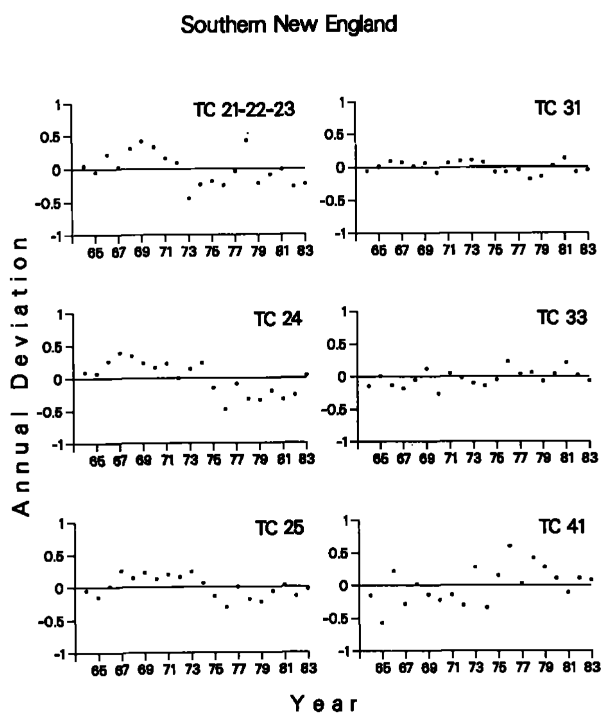

FIGURE 8.—Deviations in annual fishing power from the 1964–83 20-yr mean for major vessel tonnage classes fishing on Southern New England grounds.

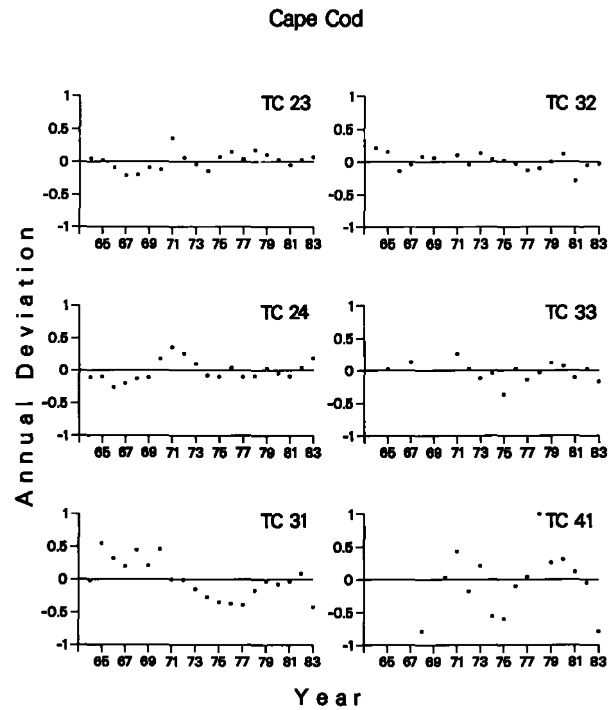

FIGURE 9.—Deviations in annual fishing power from the 1964–83 20-yr mean for major vessel tonnage classes fishing on Cape Cod grounds.

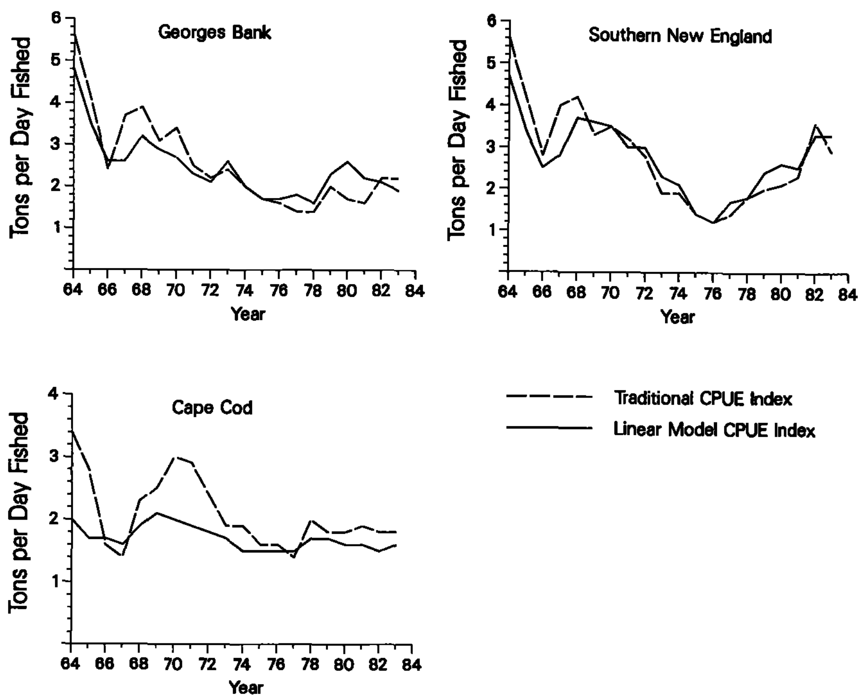

FIGURE 10.—Trends in annual yellowtail flounder CPUE (metric tons per day fished) calculated with traditional CPUE based on Lux (1964) and annual coefficients (linear model CPUE).

TABLE 6.—ANOVA results obtained from a three-way linear model incorporating year, quarter, and tonnage class for Georges Bank, Southern New England, and Cape Cod stocks of yellowtail flounder.

Source	df	Sum of squares	Mean square	F value	*P*
		Georges Bank			
With interaction					
Model	211	1,432.92	6.79	29.53	<0.01
Year	19	908.42	47.81	207.88	<0.01
Qtr	3	107.36	35.79	155.59	<0.01
TC	9	84.24	9.36	40.70	<0.01
Yr*Tc	103	116.81	1.13	4.93	<0.01
Yr*Qtr	57	202.29	3.55	15.43	<0.01
Qtr*Tc	20	13.80	0.69	3.00	<0.01
Error	18,437	4,171.68	0.23		
Total	18,648	5,604.60	0.30		
Without interaction					
Model	31	1,100.02	35.48	147.83	<0.01
Year	19	908.42	47.81	199.21	<0.01
Qtr	3	107.36	35.79	149.11	<0.01
TC	9	84.24	9.36	39.00	<0.01
Error	18,617	4,504.58	0.24		
Total	18,648	5,604.60	0.30		
		Southern New England			
With interaction					
Model	217	2,859.95	13.18	33.79	<0.01
Year	19	2,085.95	109.79	281.50	<0.01
Qtr	3	111.50	37.17	95.30	<0.01
TC	6	59.80	9.97	25.56	<0.01
Yr*Tc	114	257.12	2.26	5.78	<0.01
Yr*Qtr	57	304.89	5.35	13.72	<0.01
Qtr*Tc	18	40.69	2.26	5.80	<0.01
Error	26,879	10,612.21	0.39		
Total	27,096	13,472.16	0.50		
Without interaction					
Model	28	2,257.25	80.62	196.62	<0.01
Year	19	2,085.95	109.79	267.77	<0.01
Qtr	3	111.50	37.17	90.66	<0.01
TC	6	59.80	9.97	24.31	<0.01
Error	27,068	11,214.91	0.41		
Total	27,096	13,472.16	0.50		
		Cape Cod			
With interaction					
Model	247	2,438.73	9.87	24.68	<0.01
Year	19	166.49	8.76	21.91	<0.01
Qtr	3	174.44	58.15	145.37	<0.01
TC	9	1,331.92	147.99	369.98	<0.01
Yr*Tc	135	526.18	3.90	9.74	<0.01
Yr*Qtr	57	167.62	2.94	7.35	<0.01
Qtr*Tc	24	72.09	3.00	7.51	<0.01
Error	19,097	7,731.24	0.40		
Total	19,344	10,169.97	0.53		
Without interaction					
Model	31	1,672.84	53.96	122.64	<0.01
Year	19	166.49	8.76	19.92	<0.01
Qtr	3	174.44	58.15	132.15	<0.01
TC	9	1,331.92	147.99	336.34	<0.01
Error	19,313	8,497.13	0.44		
Total	19,344	10,169.97	0.53		

TABLE 7.—Tonnage class, quarter, and year coefficients derived from a three-way linear model for the 1964–83 period for yellowtail flounder stocks on Georges Bank, Southern New England, and Cape Cod grounds.

	Georges Bank	Southern New England	Cape Cod
Tonnage class			
21	—	0.92	0.32
22	—	0.92	0.50
23	—	0.92	0.57
24	0.57	0.93	0.80
25	0.80	0.96	1.00
31	0.96	0.92	1.03
32	1.00	1.00	0.84
33	1.08	1.09	1.00
41	1.13	1.05	1.24
42	1.19	—	—
Quarter			
1	0.96	1.00	1.07
2	0.89	1.06	1.15
3	1.09	1.18	0.90
4	1.00	1.00	1.00
Year			
1964	1.00	1.00	1.00
1965	0.73	0.72	0.84
1966	0.55	0.54	0.84
1967	0.54	0.60	0.81
1968	0.68	0.79	0.93
1969	0.61	0.77	1.06
1970	0.58	0.75	1.00
1971	0.49	0.63	0.95
1972	0.45	0.65	0.88
1973	0.55	0.49	0.84
1974	0.42	0.45	0.77
1975	0.36	0.30	0.72
1976	0.37	0.25	0.76
1977	0.37	0.36	0.74
1978	0.34	0.39	0.83
1979	0.48	0.52	0.85
1980	0.55	0.56	0.78
1981	0.46	0.54	0.80
1982	0.44	0.71	0.77
1983	0.40	0.70	0.78

DISCUSSION

The analytical approach adopted in this paper is based on the hypothesis that CPUE of yellowtail flounder differs among the various tonnage classes of vessels and geographic regions associated with the fishery. In all of the analyses, the null hypothesis (i.e., no significant differences) was rejected only when the probability of obtaining a greater F statistic was <0.01. Even at this probability level, statistically significant results were often obtained when differences among variable levels appeared to be minimal due primarily to the large number of observations included in most analyses.

The initial series of ANOVAs, based on pooled CPUE data from all statistical areas encompassing the three stocks, provided sufficient evidence to reject the null hypothesis. In each of the 20 years analyzed, the main effects of tonnage class and statistical area represented highly significant ($P < 0.01$) sources of variation. The tonnage class-area interaction term was also highly significant in all cases, implying that vessels of various tonnage classes exhibit different CPUE trends relative to each other in different areas.

The initial results established the basis for further investigations. In subsequent analyses, the data were grouped to test the null hypothesis that no significant differences in CPUE existed among the three traditionally accepted stock definitions (Georges Bank, Southern New England, and Cape Cod). The highly significant differences obtained in 19 out of 20 years indicate that catch rates differ among the three stocks. The resulting highly significant tonnage class-stock area interaction term obtained from the ANOVAs in all years suggests that standardization of CPUE among tonnage classes should be performed separately for each stock.

Analysis of variance within each stock provided the final basis for performing the standardized CPUE calculations. In these tests, the rejection of the null hypothesis for tonnage class main effects in all years for each stock suggests that separate fishing power coefficients must be calculated for each tonnage class even though the coefficients are similar in many cases. The ANOVA results also indicated that differences in CPUE among statistical areas within each stock were highly significant in 80% or more of the years implying that, within each stock region, yellowtail abundance is not homogeneous. This is not surprising since yellowtail flounder are prevalent only on certain grounds within each geographic region. Further analyses of the data by depth indicated no overall significant differences in CPUE between the two primary depth zones (1–55 m and 56–110 m) where yellowtail flounder are consistently caught.

The infrequent number of significant interactions on Georges Bank and Cape Cod grounds relative to Southern New England (Table 4) suggests a greater independence of the tonnage class and area main effects with respect to CPUE, i.e. both large and small vessels exhibited relatively similar changes in mean CPUE among statistical areas within each stock. In choosing data sets for computing fishing power coefficients we sought to minimize the amount of interaction among the vessel tonnage classes and geographic areas involved. This criterion was met to a greater extent for the Cape Cod and Georges Bank stocks than for the Southern New England stocks. It appears that yellowtail flounder inhabiting this region are subject to a more complex set of interactions perhaps due to temperature and bottom type. We decided, however, to accept the results for each of the three stocks and proceed with the calculations of fishing power coefficients.

Annual fishing power coefficients computed for each vessel tonnage class fishing on Georges Bank, Southern New England, and Cape Cod grounds provided a basis for examining the consistency in relative fishing power of individual tonnage classes over time. Annual deviations for Georges Bank and Southern New England grounds indicated a gradual change in relative fishing power of most tonnage classes between 1964 and 1983, and tests for autocorrelation of residuals indicated significant time effects. On these grounds, larger vessels exhibited higher catch rates relative to the standard in the later years as compared with the earlier years. Since many of the larger vessels have been replaced in recent years by newer vessels which are, presumably, equipped with more sophisticated electronics, any attempt to relate CPUE to stock abundance must account for such technological advances.

Similarly, changes in seasonal availability are often great enough to mask interannual variation in stock abundance. Thus, the presence of significant tonnage class-season interactions may be explained by the ability of certain vessel classes to effectively target seasonal concentrations. Since peak spawning of yellowtail flounder occurs during late spring (Lux 1964), the presence of high seasonal coefficients during the second and third quarters is not surprising.

By specifying the model to include tonnage class, annual, and seasonal components, we have attempted to account for technological and seasonal availability factors which interact with temporal changes in abundance. Although other factors could be incorporated in the model to account for a larger portion of the variation in CPUE, analyses of historical commercial fishing operations of this type are often limited to those attributes which can be directly linked to landings records (Kimura 1981; Westrheim and Foucher 1985). An alternate approach adopted by Stern and Hennemuth (1975) involved the use of a study fleet of selected vessels whose characteristics and fishing practices were closely monitored.

In our study, factors were selected for inclusion in the model based on prior knowledge of fleet characteristics and seasonal and spatial distribution patterns of the species. Despite this, the three attributes incorporated in the final model accounted for 15–25% of the total variation in CPUE, depending on the stock. Undoubtedly, other factors such as experience of the captain, net design and rigging, and variation in local fish abundance contribute substantially to overall variation in catch rates.

Differences between the annual CPUE estimates based on Lux's original fishing power coefficients and the recalculated indices occur in many cases because of shifts in the vessel composition of the fleet over the past 20 years. The inclusion of larger vessels in the more recent years, particularly on Georges Bank and Southern New England grounds, may account for the consistently higher CPUE estimates obtained for these areas since the mid-1970's. On Cape Cod grounds, CPUE estimates differ substantially prior to this time. Lux (1964) has stated that a relatively low proportion of the landings from this area were used in his CPUE computations and, consequently, the indices were not considered to be as valid a measure of relative abundance as those obtained for Georges Bank and Southern New England. Our analyses for Cape Cod grounds, based on data for the period since 1964, are subject to the same concerns since a large proportion of the yellowtail flounder landings continues to be taken incidentally.

Although the revised standardized CPUE estimates presented in this paper are based on a different standardization technique, trends are generally similar to those obtained previously. The revised procedure, however, accounts for seasonal and technological influences and insures complete representation of all vessel classes engaged in the yellowtail fishery.

ACKNOWLEDGMENTS

We wish to sincerely thank Stephen H. Clark for his advice throughout this study, and for critically reviewing the manuscript. Michael J. Fogarty reviewed the final draft and advised on statistical procedures. We are also grateful for the suggestions provided by two anonymous referees.

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